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APPLICATION FOR LETTERS PATENT
OF THE UNITED STATES

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TITLE OF INVENTION: SYSTEM AND METHOD FOR
UNIVERSAL EXTENSIBILITY THAT
SUPPORTS A PLURALITY OF
PROGRAMMABLE LOGIC CONTROLLERS

TO WHOM IT MAY CONCERN, THE FOLLOWING IS
A SPECIFICATION OF THE AFORESAID INVENTION

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**SYSTEM AND METHOD
FOR UNIVERSAL EXTENSIBILITY THAT SUPPORTS A
PLURALITY OF PROGRAMMABLE LOGIC CONTROLLERS**

5 **CROSS-REFERENCE TO RELATED APPLICATIONS**

This application claims the benefit of U.S. Provisional Patent Application No. 60/413,682, filed on September 26, 2002, incorporated by reference herein, in its entirety.

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DESCRIPTION

BACKGROUND OF THE INVENTION

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Field of the Invention

The invention generally relates to a software development platform, and more particularly, a software development platform for providing a universal unifying interface to a plurality of programmable logic controllers.

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Background Description

Programmable Logic Controllers (PLCs) typically include a customized piece of hardware that has an instruction set geared for the industrial control industry. This piece of hardware is often referred to as a Hard PLC. The programming language is usually ladder logic or some other language that is appropriate for the control application. The programs (control programs) usually

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involve the manipulation of memory areas in the PLC that are tied through other specific pieces of hardware (I/O modules) to machinery such as, for example, switches, pumps, motors, machines, etc. These I/O modules are usually mounted on a rack and can be accessed over a network.

5 In recent years, the control industry has expanded to take advantage of the power of the Personal Computer (PC). A Soft PLC is a software version of the Hard PLC. Instead of having actual circuitry boards that execute the control program, a software program that runs on the PC executes the program. Additional cards may be inserted into the PC chassis to allow for access to the I/O
10 modules. The Soft PLC will interface with these cards which, in turn, interface with the I/O modules.

 There is another version of the PLC called a Slot PLC. This is a piece of hardware that is in the form of a card that can be inserted into a PC's chassis. The Slot PC contains substantial portions of hard PLC circuitry (or similar) and
15 behaves substantially like a Hard PLC, but has a limited amount of accessibility and interaction to any other applications on the PC. Essentially, it is a Hard PLC on a PC card form with limited interaction with software running on the PC itself.

 However, developing applications software for each of these types of PLCs can be exceedingly costly since the interfaces between PC applications and
20 each type of PLC are different and the programming methodology within each type of PLC may be substantially different. Providing enhancements to these different types of PLCs, so that they are evolved with the same or similar features,

is difficult and expensive. Design and development time, cost, and reliability issues to replicate functionality for each of these PLC types are an impediment to efficient and cost-effective life-cycle product development.

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SUMMARY OF THE INVENTION

In an aspect of the invention, a method is provided for an open development kit. The method comprises the steps of sending a specific formatted load application request message from a programmable logic controller (PLC) to an open development kit (ODK) subsystem, and converting the specific formatted load application request message to a generic formatted load application request message. Further included are the steps of sending the generic formatted load application request message from the ODK subsystem to an application for requesting an extension to be loaded and requesting execution of the application.

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In another aspect of the invention, a system for providing an open development kit is described. The system comprises a means for sending a specific format load application request message from a programmable logic controller (PLC) to an open development kit (ODK) subsystem, a means for converting the specific format load application request to a generic format load application request message by the ODK subsystem. Further provided are a means for sending the generic load request from the ODK subsystem to an application requesting an extension to be loaded and a means for requesting execution of the application.

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In another aspect, a system for providing an open development kit is described.

The system comprises a means for sending a specific format load application request message from a programmable logic controller (PLC) to an open development kit (ODK) subsystem and a means for converting the specific format load application request to a generic format load application request message by the ODK subsystem. Further included are a means for sending the generic load request from the ODK subsystem to an application requesting an extension to be loaded and a means for requesting execution of the application.

In another aspect of the invention, a kit for open development is provided. The kit comprises a means for receiving a specific formatted message from a programmable logic controller (PLC), a means for converting the specific formatted message to a generic formatted message and a means for sending the generic formatted message to an application for execution.

In another aspect of the invention, a computer program product is provided comprising a computer usable medium having readable program code embodied in the medium and includes a first computer program code to send a specific formatted load application request message from a programmable logic controller (PLC) to an open development kit (ODK) subsystem and a second computer program code to convert the specific formatted load application request message to a generic formatted load application request message. Also included are a third computer program code to send the generic formatted load application request message from the ODK subsystem to an

application for requesting an extension to be loaded and a fourth computer program code to request execution of the application.

BRIEF DESCRIPTION OF THE DRAWINGS

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The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of embodiments of the invention with reference to the drawings, in which:

Figure 1 is a diagram of an exemplary PC based PLC environment;

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Figure 2 is a block diagram of an embodiment of the invention;

Figure 3 is an illustrative diagram showing the elements of a virtual CPU and services in the PC-based PLC environment including general categories, according to the invention;

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Figure 4 is a block diagram of an embodiment showing components involved to implement the RTX (real-time) version of an open development kit (ODK), according to the invention;

Figures 5A-5C is a flow diagram showing steps of an embodiment for using the invention; and

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Figure 6 is a sequential flow diagram of an embodiment showing the steps and interaction between components of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

The invention provides an Open Development Kit (ODK) package, for use
5 on a personal computer (PC) or similar computing platform, which is capable of
establishing universal extensibility and interfaces (I/F) to a plurality of different
types of PLCs. The PLCs may include Soft PLCs, Hard PLCs, and Slot PLCs.
The ODK permits users to create evolutionary features or modifications to
existing features and functions in a common application software package that
10 interacts and controls PLC functions, which may be a Soft PLC, Hard PLC, or
Slot PLC.

Figure 1 is a diagram of an exemplary PC-based PLC environment,
generally denoted by reference numeral 1. A PC Station 5 includes an expansion
bus 10 with PC slots 20 that accept board based Slot PLCs, interfaces for Hard
15 PLCs or interface adaptor cards for soft PLC implementations. Communications
15 for interfacing and controlling devices in a manufacturing environment, or the
like, are provided by each board in the PC slots 20, as necessary. The
communications 15 may include various network interfaces and topologies, e.g.,
Ethernet or PROFIBUS-DP (IEC 61158) in communication with controlled
20 devices.

Figure 2 is a block diagram of an embodiment of the invention. The
embodiment of Figure 2 includes an ODK application 200 which is a software

control enhancement program for controlling devices (e.g., machinery, industrial controls, etc.) in a PLC environment and may be employed using the PC-based PLC environment of Figure 1. Also included in Figure 2 are the various PLC types which may typically interface in a slot of a PC and comprise a Hard PLC ODK I/F 205 that provides control and interaction with a Hard PLC 210. A slot PLC ODK I/F 215 provides control and interaction with a Slot PLC 220 that resides in the PC platform bus slot. A Soft PLC I/F 225 provides control and interaction with a Soft CPU 230. The Soft CPU 230 may include a Windows based virtual CPU, WinAC Basis 235 and/or WinAC RTX based virtual CPU 240. The invention provides a single common development tool to generate ODK applications (e.g., 200) for all the WinAC product types (e.g., 210, 220, 230).

The ODK package, also known generally as WinAC ODK, provides a single engineering tool set for use with the several types of PLC products instead of having separate tool sets for each of the PLC products. The ODK uses an operating system such as, for example, Windows® (Windows® is a registered trademark of Microsoft Corporation) which provides the software environment for application software to run under and interact with the various types of PLCs and I/O devices. The ODK tool kit permits users or developers to create projects that are directed to enhancing the control program of one or more of the various types of PLCs.

The components of the tool set include the following, for example:

- A generic Application Wizard.

- Header files to be included in the application project to provide the ODK interface template.
- Library files to be included in the application providing access to the ODK interface in the WinAC product.
- 5 • Example projects demonstrating the ODK functionality.

The Application Wizard includes a common tool for generating applications for the various types of WinAC compliant PLC products. Two modes are provided. First, a Real Time Dynamic Link Library (RTDLL) project may be generated for those users desiring to take advantage of a Real Time
10 environment provided with a WinAC RTX product. Second, a Dynamic Link Library (DLL) project may be generated for non-Real-Time based applications.

The generated projects provide access to the standard ODK interface of the various types of PLC products. Code stubs are provided in the project for the CPU to ODK application calls. The header files and libraries included in the
15 projects provide access to the ODK application to CPU calls. The generated project also contains helper classes for accessing Step 7 type data from the buffer that is passed between the CPU and the ODK application. Step 7 is another program which is used to write the control program for the PLC and has specific formats for data and programming constructs that are known to one of ordinarily
20 skill in the art. Step 7 is a programming tool for PLCs.

The Hard PLC 210 is typically considered a more traditional type of PLC, as discussed previously. Soft PLCs may comprise different embodiments and

may include, for example, WinAC Basis (Basis CPU 235) and WinAC RTX (RTX CPU 240). The WinAC Basis is a Soft PLC that is used when Real-Time functionality is not required or necessary for the control process of industrial devices, or the like. For those applications that require (or more reliable scanning is desired) Real-Time processing, WinAC RTX may be used. The Slot PLC (Slot CPU 220) is typically a hybrid of the Hard PLC and the Soft PLC as previously described.

In addition to automatically generating the above functionality, the Application Wizard walks an application developer through the generation of code stubs for the following tasks, for example:

- Subcommands which allow the CPU to execute specific actions in the application. These subcommands are a case statement in the extension code. Each subcommand has a unique value associated with it. When the subcommand is passed in to the extension application using the Execute command from the PLC control program, the subcommand passes through the case statement so that the appropriate task is accomplished in the extension application.
- Asynchronous processes which allow the execution of actions outside of the main line of execution. Each of these processes is created on a unique thread. This enables tasks to be accomplished outside of the main execution thread (using the Execute command)

from the PLC control program. These processes may interface with third party devices, perform some lengthy calculation, or perform some other time intensive task that would adversely affect the scan cycle. At creation time, the thread priority can be set as higher or lower than the main execution thread priority.

- Asynchronous monitoring which allows the application to monitor actions outside of the main line of execution. These tasks are similar to the asynchronous processing mentioned above.

However, they differ because these are monitoring tasks and they will monitor for events that occur. When the specified event occurs, the asynchronous monitor task will perform some task in the extension application.

The features of the WinAC ODK toolkit product remove the need for ODK products to be created for each WinAC CPU product (e.g. WinAC RTX ODK, WinAC Basis ODK, or Slot PLC). The developer now has a single common tool to generate ODK applications for all of the WinAC CPU product types. The ODK also provides the ability to generate an ODK project which, in turn, will generate a DLL which can be used with any of the WinAC ODK capable products. The generated DLLs provide the linkages between the application software generated by the developer and the interfaces to each of the various PLC types as shown in Figure 2. These functions are described in more detail with reference to Figures 5A-6. The application need only be developed once and may then be targeted to more than one type of PLC, instead of developing the same

application for each type of PLC. The DLLs produced by the ODK provide the transformational interfacing as needed to each PLC type.

The ODK system is installable without changing the CPU Proxy application and maintains backward compatibility with previous versions, e.g., it allows interaction with common object module (COM) objects where required by the application. The interface is provided as a direct in-process interface for best performance and to avoid the overhead of marshalling, copying, and issues of memory allocation.

There are behavior differences between DLLs in NT and DLLs in RTSS. The design minimizes dependencies on DLL differences. DllMain is minimized or eliminated in the ODK. Callback dependencies (dependencies in the DLL on functions or class interface in the module loading the DLL) are also minimized.

Figure 3 is an illustrative diagram showing the elements of a virtual CPU and services in the PC-base PLC environment including general categories as operating system interfaces, I/O interfaces, file system interfaces, communication interfaces, programming interfaces, and extensibility interfaces. These interfaces allow the basic "CPU" of the virtual machine to be expanded and enhanced by adding other software pieces. The virtual machine (e.g., SIMATIC MC7 Virtual Machine) is written in portable code that can be moved to different types of hardware and typically executes without modifications. The interfaces described above may be changed as necessary by those of ordinary skill, the virtual machine is moved to different hardware platforms to allow it to interface with its altered environmental surroundings. The extensibility interface provides the extensibility of the operating environment to permit the generic operation of a PLC

application to interface with the different types of PLCs as shown in Figure 2. The
extensibility interface permits user libraries, system blocks (SFBs/SFCs), and DLL to be
dynamically and statically linked as necessary to translate commands and events from a
user application (which may be a uniquely created application) to the PLC interfaces
5 appropriate to the type of PLC. This provides for replaceable functionality as necessary
for PLCs.

Figure 4 shows the components involved to implement the RTX (real-time)
version of ODK. Figure 4 shows two portions, a RTX portion which is essentially a real-
time environment (deterministic environment with fixed scan cycles), generally denoted
10 by reference numeral 300 (below the partition line 389) and a Windows portion,
generally denoted as reference numeral 350 (above the partition line 389) which is an
essentially non-real time (non-deterministic with non-fixed scan cycles) operating
environment for certain PLC applications. The RTX portion 300 includes an ODK DLL
305, an ODK System Block (SB) Add-on DLL 310 for implementing a generic interface
15 to the WinLC SBLoader 315. The generic interface allows for the WinLC SBLoader 315
to load any software component for any type of PLC. The WinLC SBLoader 315 loads
system blocks.

Figure 4 also shows a Virtual CPU 320 (e.g., V7) for execution of the loaded PLC
control program in a real-time mode, and a WinLC RTX framework 325 which includes
20 providing the operating environment for RTX services in the real-time side and includes
coordinating process interaction with the non-real time operating environment, e.g., 350.

The coordination of the two operating system environments may be performed via bidirectional messaging interface 375 (e.g., SMMail).

The Windows portion 350 (i.e., non-deterministic non-real time operating environment with non-fixed scan cycles) includes user ODK COM objects 360 and ODK Debug DLL's 355, ODK RTX Proxy DLL 365 that is responsible for communicating through shared memory 366 to the ODK SB Add-on DLL 310 and for implementing the ODK COM interface 367, and WinLC RTX Proxy 370 that provides a view within Windows to the real-time side. The COM object is an extension application using Microsoft's COM technology. The COM object functions the same as the DLL extension application in a real-time system 305. The WinLC RTX Proxy 370 communicates and coordinates with the RTX side 300 via the messaging interface 375.

A Soft PLC instance includes the area in the box 380. For each instance of a soft PLC application running in the PC-based PLC environment 1, the components of 380 may be instantiated.

Control programs often use system blocks. These are blocks that are provided by the programming tool (in this case Step 7) that perform predefined tasks. System blocks include SFBs (System Function Blocks), SFCs (System Functions), and SDBs (System Data Blocks). SFBs and SFCs provide pre-written code with a defined interface to the code similar to API calls in the Windows programming environment. SDBs hold system data that may be accessed. The ODK subsystem interface is implemented by providing two SFBs that may be called from one or more of the PLC control program. One SFB is the Create call. This SFB may accomplish steps 400 through 435 of Figure 5A-5C, and is

called only once from the control program. The second SFB is the Execute call and it is responsible for items 445 through 460, of Figures 5A-5C. This second SFB can be called multiple times in the control program. The loading of system blocks may be implemented by one of ordinary skill in the art.

5 Responsibility for block generation is in the WinLC SBloader 315. This class is able to load any "system blocks" including SFBs, SFCs, SDBs (i.e. SDB1), or DBs. Product specific code for block generation is removed from the CPU personality, the block manager. A product specific WinLC SBLoader 315 is part of the application framework and typically is not part of the Virtual CPU 320. Some standard library
10 functions are included in the Virtual CPU 320 to create and load classes of System Function Blocks. For example, three functions may be LoadCommonSysBlocks, LoadPMCSysBlocks, LoadPrintSysBlocks. WinLC SBLoader 315 also obtains the names of DLLs to load. These DLLs are required to have a Load function, similar to the library functions, to dynamically add blocks.

15 The names of add-on DLLs are typically maintained in a system registry. The registry entry may be the one passed in the call to OSLoadLibrary (for accessing library such as 307) so the location of the DLL is completely under Setup control. This information is obtained from the registry using an extended PCStation interface.

 The CPU invokes methods in the WinLC SBLoader 315 at the appropriate time
20 during construction to create and link the system blocks. The CPU Proxy 370 is responsible to Load and Free the ODK RTX Proxy DLL, but, in implementations, has no other interaction with the DLLs. Using a DLL proxy instead of a separate executable

simplifies the creation and coordinating of executables and executable lifetimes. For example, the proxy DLLs come into existence and go out of existence with the CPU Proxy application in this case, so the startup rules are automatically the same as the CPU Proxy 370. Also, if the CPU Proxy 370 is a service, then so is the proxy DLL.

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ODK Components

The ODK components include the ODK SB Add-on DLL 310 and the ODK RTX Proxy DLL 365. The ODK RTX Proxy DLL 365 is responsible for communicating through shared memory to the ODK SB Add-on DLL 310 and implementing the ODK
10 COM interface 360. The ODK SB Add-on DLL 310 implements the generic interface to SBI loader 315 and the two ODK specific SFRs that were defined earlier in this document.

ODKServer is a class which implements an OSSharedMemory interface, e.g., 366, to ODK SB Add-on DLL 310 and has a dispatch thread which can support COM
15 calls. ODKServer implements the create and execute and ODK IWinLCService callback functions. A separate Create function is called to do the minimal setup required to receive a command from the ODK DLL 305.

Figures 5A-5C are flow diagrams showing steps of an embodiment for using the invention, beginning at 400. Figures 5A-5C may equally represent a high-level block
20 diagram of components of the invention implementing the steps thereof. The steps of Figures 5A-5C may be implemented on computer program code in combination with the appropriate hardware. This computer program code may be stored on storage media such

as a diskette, hard disk, CD-ROM, DVD-ROM or tape, as well as a memory storage device or collection of memory storage devices such as read-only memory (ROM) or random access memory (RAM). Additionally, the computer program code can be transferred to a workstation over the Internet or some other type of network. Figures 5A-5C may be implemented, for example, using the components of Figure 4 and the PC-based PLC environment of Figure 1.

Figure 6 is a sequential flow diagram of an embodiment showing the steps and interaction between components of the invention. The steps of Figure 6 substantially parallel the steps of Figures 5A-5C and these parallel steps are reflected by corresponding reference numerals, for example, Figure 5, step 405 parallels step Figure 6, step 405'. The sequential flow diagram of Figure 6 illustrates, by way of example, sequencing of the steps from perspective of PLC interface 390 (which may be one of 210, 220, or 230), a ODK subsystem 392 (which may be one of 205, 215, 225 and include the components of 310 and 365) and a customer or user application 394 (e.g., 200). The ODK subsystem 392 provides a unifying function of commands and requests from the various type of PLC that may have different command and request structures. The ODK subsystem 392 converts specific formatted PLC commands and messages as necessary to a generic format for presentation to the application 394, and conversely, reconverts commands and requests from the application 394 to PLC interfaces 390, as necessary, to specific formats for the various types of PLCs', according to their type.

Continuing simultaneously with Figure 5A-5C and Figure 6, at step 405, the PLC 390 sends a request to the ODK subsystem 392 to load the application DLL(s) that is to

be included in the scan cycle of the PLC 390. The DLL(s) provide the open communication into the scan cycle of the PLC 390. At step 410, the ODK subsystem 392 loads the DLL(s) or extensions from the customer application 394 by sending a request to load the extensions. At step 415, the ODK subsystem 392 calls the Initialize function in the application and initializes a list of callback function pointers for use as function calls back into the ODK subsystem 392 by the application 394.

At step 420, the ODK subsystem 392 calls a Create function in the application which performs initialization of functionality required when the DLL(s) is loaded. At step 425, a check is made whether a stop to run transition has occurred in the PLC 390. If a transition has occurred, then at step 430, the PLC 390 sends a request to the ODK subsystem 392 to activate the application 394. At step 435, the ODK subsystem 392 calls the Activate function in the application 394 which performs and executes functionality required after loading the DLL(s) and required before the DLL(s) actually begin its normal scan cycle execution.

At step 440, a check is made whether there are requests for Application execution in the PLC. If not, processing continues at step 490, otherwise execute the requests. As shown by parallel flow lines in Figure 5B, execution (from the PLC 390) requests may be performed at the same time as application 394 requests. At step 445, the PLC 390 requests that the ODK subsystem 392 execute the application. The command to be executed along with input areas and output areas are provided, the ODK converts as necessary the command to a generic command. At step 450, the ODK subsystem 392 calls the Execute function in the application 394 and passes the generic command and

input/output areas to the application 394. Control is passed to the application 394 at this time.

At step 455, the application 394 executes the requested command. The input area is read and the output area is written, as necessary. After completion of the execution of the command, the application 394 returns the response, data, and control back to the ODK subsystem 392. At step 460, the ODK subsystem 392 converts the generic response and parameters into a format suitable for the target PLC type and returns these results of the Execute request to the PLC 390.

At step 465, a check is made whether there are any requests for information for the PLC 390 in the application 394. If not, the process waits for a PLC state change to occur or requests for PLC information to occur. Otherwise, the process executes the requests, and at step 470, the application 394 requests information from the PLC 390 using the callback function pointers established at step 415. The application 394 calls an appropriate selected function as needed in the ODK subsystem 392 using these callback function pointers. At step 475, the ODK subsystem 392 executes the requested function specified by the application 394 and may convert the generic request as necessary for the target PLC type and performs the requested task in the PLC 390 (e.g., sends a request to PLC 390) or retrieve the desired information from the PLC 390. At step 480, the ODK subsystem 392 receives a response from the PLC 390 for the request sent at step 475, and at step 485, the ODK subsystem 392 may convert the response to a generic response and returns the generic response to the application 394.

At step 490 (not shown in Figure 6), the process waits until either the PLC 390

transitions from a run state to a stop state or continues processing execute and application requests (i.e., continues with steps 440 or 465 as appropriate). If a transition from a run state to a stop state occurs, then at step 495, the PLC sends a request to the ODK subsystem 392 to deactivate the application 394. At step 500, the ODK subsystem calls a
5 Deactivate function in the application 394 which performs functionality required between the time that the DLL(s) halts normal can cycle execution and the time that the DLL(s) is unloaded or started again. This is similar to an "idle" state for a DLL after it has been executed.

At step 505, if a memory clear and/or a PLC shutdown occurs then at step 510,
10 the ODK subsystem 392 calls the Release function in the application 394 which executes functionality required before the DLL(s) is unloaded. Otherwise, if a memory clear and or PLC shutdown does not occur then continue with step 425. The process may end at 515.

While the invention has been described in terms of embodiments, those skilled
15 in the art will recognize that the invention can be practiced with modifications and in the spirit and scope of the appended claims.